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Sustainable coastal management, past, present and future or how to deal with the tides

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Abstract Over the centuries communities living in the coastal areas of the North Sea and the Atlantic Ocean have made a living by using the in- and out-going tides to their benefit. They did so by letting the high tides in freely. How did this happen? Why did they do so and what lessons can be learned from these past examples of sustainable coastal management? Within the framework of rising sea level, one of the future challenges will be how long the Dutch can remain safely behind dikes and dams that have to be constantly raised. Four different coastal areas will be discussed, each with a different chronology, land use and hydrology. The first case concerns tidal landscapes in Brittany and Anjou (France). Using the incoming tides a network of channels and retention areas developed here since mediaeval times. In these basins a slow evaporation process led to high quality salt. The second example includes areas in the SW-Netherlands and the Wadden area, which have been used for grazing. How did grazing affect the development of that tidal landscape, and what happened when grazing stopped? The third example comes from former Zuiderzee polders near Kampen, where low dikes (kaden) were built. These dikes could withstand the ordinary summer tides but allowed the higher winter tides to flood the polder, resulting in sediment deposition which raised the level of the low-lying land. The article goes on to describe a fourth example which draws on the case studies presented here. The final study aims to restore the disrupted low-lying surface levels of the oldest polders to a much safer, higher level. By allowing high tides to enter the polders in a regulated way, sediment deposition can be re-introduced and the level of the polder can be raised. Rather than completely excluding the tides, the regulated flooding deposits sediment builds up the level of the polders, thus making them easier to defend.

Keywords France · The Netherlands · Salt marshes · Arable · Pasture · Salt making · Dike building · Sustainability · Sea level rise

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Introduction

Over the centuries communities living in the coastal areas of the North Sea and the Atlantic Ocean have made a living by using the in- and out-going tides to their benefit. They did so by letting the high tides in freely. How did this happen and why? What lessons can be learned from these past examples of sustainable coastal management for the future? Within the framework of rising sea level, one of the future challenges is the question of how long the Dutch can remain safe behind dikes and dams that have to be raised continuously. Three coastal areas will be discussed, and although they differ in terms of space, time, land use and hydrology, they share some important common features. They were all formed through tidal impact that led to the deposition of a thick clay layer, and they were then transformed by man into highly productive landscapes. All of this produce in terms of salt, wheat and diary products soon became market orientated, because these coastal lands were either close to big towns or markets or could be reached by ship very easily. As this highly commercial type of land use used up a lot of space, these coastal lands remained sparsely populated. And because their market orientation guaranteed sufficient financial input, they could easily develop a particular kind of flood control and water management. But in spite of these common characteristics there were significant differences between the risk management of the three coastal lands. Finally, there were unanticipated links between at least two of the landscapes during the past, which will be discussed below. This research builds upon earlier studies which cover many aspects of the three examples, including weather conditions of the past (de Kraker 2005, 2006), land ownership and exploitation and dike maintenance and salt making in the south western Low Countries which was closely linked to the Atlantic coast of France (de Kraker 2007b).

The first example is taken from the salt marsh areas of Brittany and Anjou, where for centuries salt making has been the main livelihood. Incoming tides brought in salt water which was then evaporated. The second example is taken from Kampereiland, in the Netherlands; this is the mudflat and salt marsh area in the mouth of the river IJssel. Since the late fourteenth century this area has been developed into a commercial livestock and dairy region. Here the incoming tides had a multiple use. The last example is the odd one. It is the area where salt marshes were transformed into a commercial farming area by putting an end to the incoming and outgoing tides. This example also enables us to better assess the benefits and drawbacks of the three areas (Fig. 1).

First, the general issues will be further discussed along with their background. Then the main features of three areas will be presented separately, including a discussion of how they functioned. In order to know how effective or/and cheap coastal management of the past really was and what the close relationship between livelihood, risks and sustainability was, the three coastal areas will then be compared in terms of economy and sustainability and the results will be further discussed. A ‘cost-benefit’ analysis will determine the relationship between the need to earn a livelihood, whilst weighing up the risks and sustainable constraints.

Issues and background

Across Europe a variety of different natural landscapes have provided the building blocks for a variety of cultural landscapes. Each of them, ranging from mountainous areas, sand

Fig. 1 Three areas investigated: 1. Guérande in Brittany, 2. Kampereiland and 3. Zealand Flanders located in Northern Flanders and in the south of the Dutch province of Zealand

lands, peat bog areas to coastal areas has presented its inhabitants with specific problems and limitations. Mountain communities faced erosion, land slides and river flooding. Accordingly they developed the ability to cope with these natural hazards (Veyret 2004; Lamarre 2005).

People living in sand lands faced the ever present poor soil quality and reoccurring periods of drought. Accordingly, they developed the technique of crop rotation, which they combined with sod manuring for their livelihood.

In coastal areas settlements could only be made sustainable if communities were successful in developing a type of coastal management in which the financial effort led to the introduction of the right kind of hydrological technology (de Kraker 2005).

Coastal communities faced two key problems: flooding and erosion. How did they deal with the tides? Coastal dwellers did not only have to know about the level of tides, but they also had to know about spring and storm tides which could determine the continuity of their settlements. Such extremes could also easily lead to large scale erosion of fertile fields. The higher the tides reached, the more protective measures had to be taken. If this led to the building of dwelling mounds, they had to be high enough to be safe even during the severest storm surges. From archaeological evidence it is often shown that mounds were raised at various points in time. The same is true for dike building. Regularly top levels were raised and even base lines of dikes were widened. The issue that needs to be further investigated is what the relationship is between the tidal range on one hand and the building of sea walls or perhaps dwelling mounds on the other.

Besides threats there are also opportunities in coastal areas. Because of the long term process of clay deposition, coastal areas usually have fertile soils which render them highly productive. Many a coastal area has therefore become either arable or pasture and as a result of this economic potential. The issues here are (1) how did the tidal range determine the kind of land use, and (2) how did contemporaries keep their lands highly productive?

There is still a final factor to be considered: climate change. It is assumed that there will be an increase in temperature, ranging from 1.1 to 6.4° C (Solomon et al. 2007). There will also be more precipitation, which will be even more unevenly distributed throughout the year. Larger amounts of water will be discharged through rivers flowing towards coastal areas, but we will be less able to predict the timing of the flood events, which may in future include summer floods. Climate change will increase the pressure on coastal land and has already necessitated a rethink on the usefulness of today's land use and coastal management. This rethinking requires even more attention seen from the perspective of a declining economic and financial resilience in the last few years.

In order to have some answers to the issues raised, it is useful to look at how past communities dealt with the threats and opportunities of the water, both sea and river.

Communities of the past and present

In this section the coastal landscapes of three European regions are discussed in terms of coastal management, livelihood, changes that have occurred in time, success and failures and finally the present and future situation. These coastal landscapes are salt marshes. Some of them have already gone through a long history of deposition before they were used, whilst others have not.

Example 1. Brittany (France)

France has a variety of coasts on the Atlantic and Mediterranean, some of which are erosive, whilst others have a long history of sediment deposition. Coastal Brittany on the Atlantic has both categories. This coast has hard rock headlands and areas of very extensive salt marshes. One such area is the Guėrande salt marsh, which lies north of the estuary of the river Loire [N 47°18 E 2°29].

This coastal area was intensively reclaimed from about 1,000 AD onward, and was used for salt making. The higher elevated lands were used as arable. Salt making was not a new activity in the area as already in the Iron Age sea water was evaporated in big tripods set on a fire. This bricquetage practise was carried out even throughout the Roman Period (van den Broeke 2007).Then, after centuries of low level activity, the first salines were made during the 9th century AD. The oldest known document regarding this mentions a date of 854 AD (Buron 2001, p. 56). However, is was not until the period of the Great Mediaeval Reclamation from about 1,000 onwards that several new centres of salt making developed, such as Brouage in the area of Anjou (Papy 1935) and the Batz-Guérande area.

In order to make salt, ocean water had to be evaporated. This could only be carried out in areas that were both safe and could easily be transformed. In areas where deposition was stronger than erosion, salt marshes were formed. However, these could only be used if there was a low tidal amplitude. Although the tidal range in Brittany varies from about 13 m at Mont St. Michel to less than 3 metres, Guérande has a tidal amplitude of 2.5 to 4.5. As salt making was and still is a seasonal activity, tidal amplitude from April to October seldom surpasses 3.00 metres. Finally, climate as a third factor has contributed to the salt making industry as well. In order to evaporate sea water, sunny, warm and windy weather conditions are vital. Brittany has over 2,000 h of sunshine yearly, whilst areas further south have between 2,000 and 2,500 h of sunshine (Buron 2001, p. 21).

At Guérande, the estuary has an access to the west. Most of the access is protected by a sandbar running north to south. The incoming tides then flood the salt marshes. Both the sandbar and the salt marshes have been profoundly transformed.

A network of channels and basins has emerged in the salt marshes. As soon as sea water enters the estuary and floods the salt marshes it is managed and guided through a number of confined spaces that are linked through channels and small sluices and protected by an external dike (Fig 2). This complex is a saline. Water enters through an access channel (bondre), then it continues to flow through a sluice into a space called a vasière. This is a basin where fine clay particles are still settling out of the water, but where evaporation has already started, and therefore the water here has a higher salt gradient. The water then moves through another pipe into the next basin, called a combier. Here groyns slow down its flow, which again increases evaporation and the salt gradient. Next, water moves through different small sluices into the last stage of the system with the oeillets where actual crystallisation is taking place. The dots represent heaps of crystallized salt gathered by paludiers.

Salines are made in salt marshes that have silted up high enough, reaching average high tide level or slightly higher. At such mature salt marshes the process of deposition has usually stopped. Then a circular dike is built by systematically lowering part of the salt marsh. The access channels are at an average sea level. As sea water penetrates deeper into the salines, levels of basins are a bit lower, which allows water to move to the far end naturally (Papy 1935, p. 5; Buron 2001, pp. 21, 29).

Management of the salines consists of cleaning the access channels and removing clay deposits. In addition to this, the dikes also need annual upkeep. During the non-active season (October–April) storms may cause damage and even flooding of the entire system. In such cases repairs need to be carried out before April.

Generally the salines are quite isolated in the salt marsh, because settlements are located on higher grounds. Only roads give access to the salines, and spread across them are small sheds. Therefore, weather extremes predominantly cause material damage. This separation of work from dwelling place did not call for any serious kind of coastal defence. During the storm season salines were usually abandoned.

In early mediaeval documents several monasteries owning and exploiting salines at Guérande and elsewhere on the French coast are mentioned (Galicé 2003, p. 36; Boudaud 1996). During the late fourteenth and sixteenth centuries next to ecclesiastic institutions also local feudal lords were changing salt marshes into salines. In order to do so they had needed the permission of the duke of Brittany who at some point in time focussed his economic policy on the expansion of the salt making industry (Galicé 2003, pp. 296–298). His policy of continuous granting along with taxation on salt provided quite an income. Although Buron (2004, pp. 79–90) demonstrates that ecclesiastical institutions remained important factors in salt making throughout the early modern period. For the Île de Ré area and elsewhere it is clearly demonstrated from the mid-seventeeth century onwards ecclesiastic ownership had already dropped far below 10% (Delafosse et al. 1960, p. 29). The annual maintenance and water governance remained the responsibility of those who

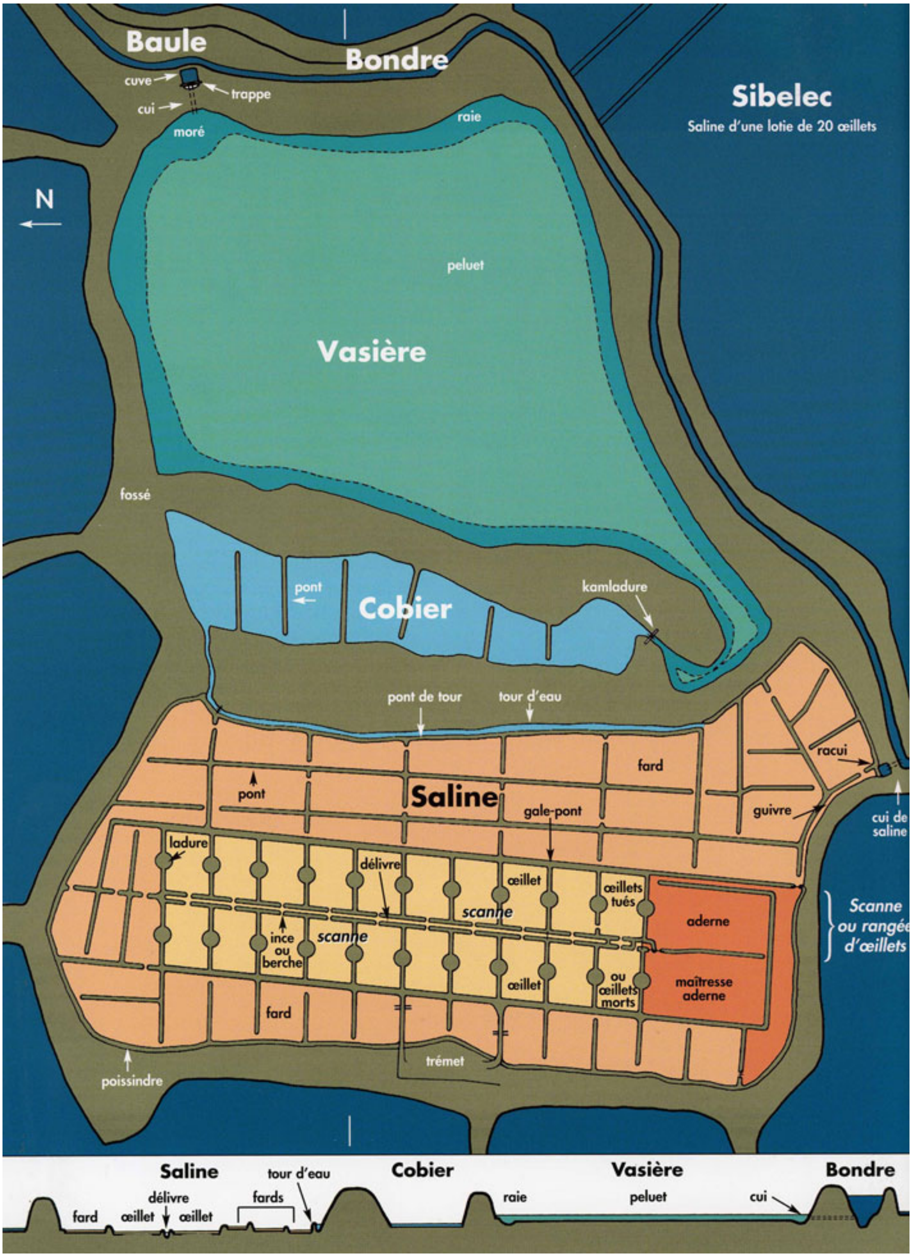

Fig. 2 A saline (Buron 2001, p. 21)

actually made the salines and to whom they were leased out afterwards as shown in detail in several lease contracts (Buron 2004, pp. 105–109).

Looking at salt making in terms of supply and demand, over a longer time period the supply of salt was rather unstable due to a range of factors. After the expansion

(1000–1300), there were setbacks during the Great Plague and Hundred Year's War (Sarrazin 1996). Then there was growth again, thanks to the very active economic policy of the Duke of Brittany, a range of new salines were reclaimed. Statistical data for the Guérande area is scarce. A saline, consisting of 22 oeillets (pans), could yield between 22 and 44 muids[1] per year (Gallicé 2003, pp. 304–306). Salt production in 1355–1356 reached a level of 3,896 muids, in 1501–1502 it reached 6,026 muids and in 1554–1555 3,048 muids were produced (Buron 2001, pp. 89–91). The religious wars of the sixteenth century, along with plague and several disastrous storm surges caused new setbacks (Buron 2001, pp. 92–93). Whilst abandoned salines were restored and new ones built again, the salt area reached its largest extent during the mid-eighteenth century. From the area of Brouage (south of La Rochelle), however, data from the eighteenth century clearly shows a sharp decline on the international market for French salt, for which the Dutch are mainly responsible. At Guérande gradual decline began a hundred years later. It was only from the 1950–1960s onwards that salt production again regained momentum, having 174 entrepreneurs exploiting 5,850 salt pans by 1999 (Buron 2001, p. 169).

Looking from the perspective of demand for salt over a longer time period, this seems to have been more stable than supply. Salt was used to conserve meat and fish, besides adding taste to a lot of other ingredients. The growing population across Western Europe and especially herring fishing in the North Sea area very much determined the price of salt. By 1300 Bruges had become a very important market for French Atlantic salt (Contamine et al. 1997, p. 248), whilst the Zealand (including Zealand Flanders) region north of the town began to substitute local salt for French salt (Hocquet 2006). In spite of the fact that herring catches could strongly vary per year, the salt prices generally went up, reaching usual peaks during the year and extraordinary peaks during periods of warfare and social unrest. Since the nineteenth century Napoleon's Blocking of the Continent, uplift of dues and growing competition from outside France contributed strongly to the downfall of salt making.

Example 2. Northern Flanders and adjacent Zealand: Zealand Flanders

In the northern part of Flanders and adjacent Zealand (The Netherlands), nowadays the southwestern part of the Netherlands called Zealand Flanders [N 51°21 E 4°18], people also started to transform the coastal area (Fig 3). This was the estuary of the Western Scheldt, where salt marshes were formed. Because the fertile clay soils guaranteed rich harvests, this area became very attractive for habitation. Tidal amplitude generally ranged from about 2.5 to 4.00 metres close to the North Sea, growing up to 6.00 metres at the far end of the estuary. Both the kind of land use and its tidal amplitude demanded a specific type of management. In order to grow wheat or any other crop, salt marshes have to be cut off from marine influence. Once the fields were established, farmers were inclined to settle on the newly reclaimed lands and therefore farms were built with large barns in which harvests could be stored safely through the winter and the stormy season. The proximity of the rising towns in Flanders and Brabant very much contributed to the reclamation of the salt marshes, which provided the towns with food and a variety of commodities such as cloth, linen, dye and also peat which was dug at random in coastal lands lying just below the clay layer.

Dikes were built throughout the area, and they had to be solid and high enough to withstand the impact of the tides. The height and impact of the tides and the necessary

[1] A muid in 1680 was about 1,150 l.

Fig. 3 Northern Flanders and Zealand about 1570 by Christiaan sGrooten (Copyright Royal Library, Brussels)

engineering had to be learnt by experience in the course of the centuries. Dike building began shortly after 1,000 AD. By the end of the middle ages dikes reached a top level of 4.00 m asl (de Kraker 2005). Besides sea water, fresh water also had to be managed. Fresh water, fed by precipitation and groundwater, was discharged through a network of ditches and a sluice. This is the way a polder was made. Floors were built in the sluices, similar to those at Guérande. Although it is presumed that dike building was initiated by local communities and local lords, storm surges and other natural phenomena regularly caused setbacks. Flooded lands were abandoned, which brought in more powerful financial institutions and even bigger feudal lords. Consequently several Cistercian monasteries and some powerful secular land owners managed to provide enough money and manpower to maintain the sea walls and the drainage canals, and continued to do so until the late fifteenth century. In practise, dike maintenance meant the addition of a new layer of straw on the seaward slope of the dike, which was fastened in the sod layer twice a year (Fig.4). The builders kept a close watch on the dikes during storm surges, and filled in the gaps made during the storm season. Usually local people carried out the day to day maintenance, whilst bigger repairs and more technical modifications were put out to tender. All expenses were paid for by those who owned land in a polder, each paying a fixed tax per acre. Successful livelihood in such a polder area depended on both a good, steady income from grain or other produce on one hand and inexpensive but reliable dike upkeep on the other. The demand for products from the polders remained high until the mid fourteenth century,

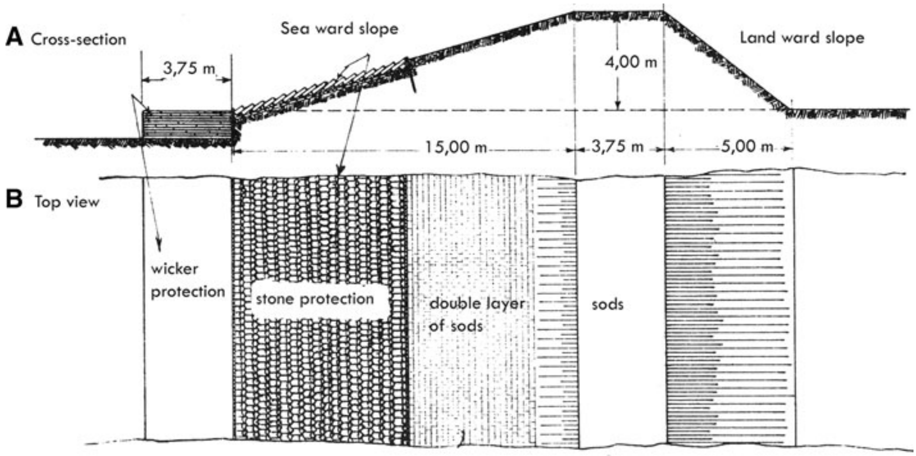

Fig. 4 Sixteenth century sea wall, Zealand Flanders (after Andries Vierlingh)

when it dropped, but demand rose again in the fifteenth century and continued to do so until the mid-seventeeth century. This stimulated the process of embankment even further.

During the sixteenth century there were two major set backs. One problem was the many storm surges, and the other was warfare. Most of the area depicted on the sixteenth century map consists of polders (Fig. 3). As this century stands out as a time of many storm surges (1509, 1530, 1570) and flooding events, contemporary maps show that many areas were submerged, and place names and churches are shown in the sea (de Kraker 2006). Moreover, during the Eighty Year's War (1568–1648) Zealand Flanders (the bottom part of the map) was severely hit, flooding over three quarters of the area. This led to a renewed process of embankment in the following centuries.

These younger polders began to look like carefully planned new landscapes with straight roads, block parcelling and where possible even long, straight dikes. Even a systematic levelling of the surface level took place first. The structure of dikes in the area discussed did not change fundamentally until the second half of the nineteenth century. From then onwards top levels were slightly raised and the seaward side was given extra protection by using basalt rock (van de Ven 1993; de Kraker 2005). It was not until after the disastrous 1953 flooding event that dikes became twice as high and wide at their base. The reasons for embankments and their maintenance never seriously changed. Technically, dike maintenance was still being carried out the same way, including gradual renovation during the nineteenth century. Over time more work was put out to tender, but in contrast to the middle ages, management had become a matter for small local landowners only, who governed their polders as a kind of free state until as recently as the mid twentieth century. Still, maintenance had to be paid for by levying a similar fixed tax per acre. Because all of the embanked lands were used as arable during the recent centuries, successful dike maintenance depended more than ever before on income from commercial crops such as grain, and increasingly also potatoes and sugar beets. After a period of low grain prices (1650–1750), the process of embankment soon resumed afterwards, gaining momentum during the nineteenth century.

Although changes occurred on the canal Gent-Terneuzen area of Zealand Flanders, it was not until the 1950s that the accelerated industrialisation along with mechanisation in agriculture fundamentally changed the employment structure of the regional economy.

In terms of land use the area is still more then 75% arable. Small villages, farms, dikes and small roads are still the main characteristics of the landscape of Zealand Flanders.

Example 3. Kampereiland area

The landscape of the coastal area of the town of Kampen is built by fluvial and marine deposits [N 52°34 E 5°54]. Kampen is located on the river IJssel which carries a lot of loose material into the former Zuiderzee (Fig 5). There it meets the salt water of the former Zuiderzee, which renders the water rather brackish. The former Zuiderzee also has a tidal amplitude, ranging from up to 1.50 in summer to about 2.50 metres in winter (Swets 1886).

These favourable conditions were used by the town of Kampen when it acquired the ‘marsh’ area in 1364. At that time the area was described as a system of shallow sand banks and bars which had hardly any economic value. In order to make it profitable, the town developed a policy of controlled embankment. A network of low, parallel dikes was built on the mudflats and then reeds and rushes were grown in the area to speed up the process of sediment deposition. If the top of the salt marsh reached sea level or slightly higher, an enclosure dike of about 1 metre high was built which would be raised a bit more in later years. Then they moved to the next piece of mudflat (Swets 1886; de Kraker 2010). In this way embankment became a kind of patchwork, but this it not shown in the present landscape. Dikes of no direct use were soon removed and the clay was used for building new ones on the mudflats. Through this process of embankment the many branches of the river delta were gradually becoming more narrow and were finally filled with sediment. Sometimes some channels were closed off, such as the Noorddiep.

Thus the area of Kampereiland became protected by dikes, and the embanked areas expanded northwards and westwards through time. However, dikes remained as low as 1.00 to 1.50 metres for a long time. The reason for this was that the embanked area could still be flooded during winter time, when water from the Zuiderzee ran higher and

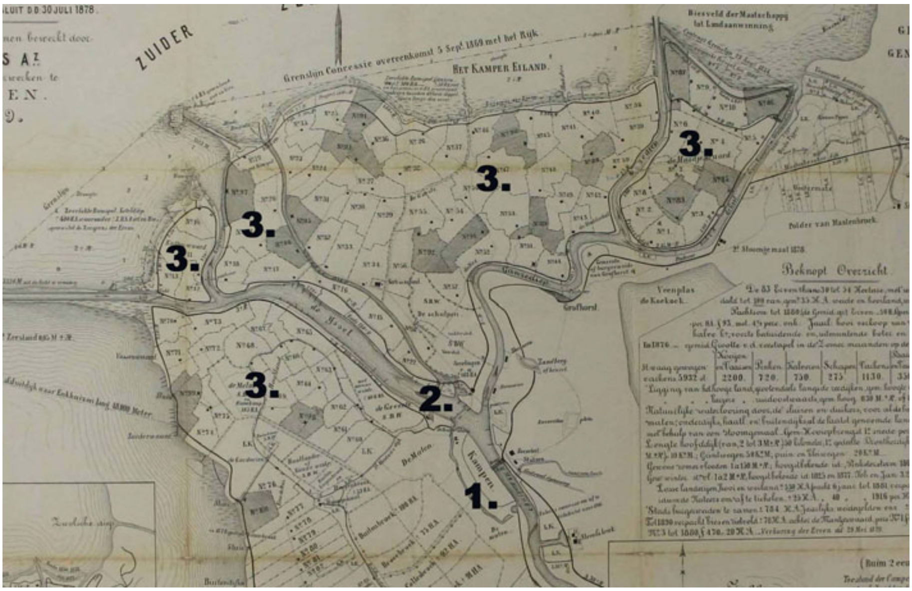

Fig. 5 Kampereiland (3), Kampen (1) and river IJssel (2) in 1879, depicted by J. Swets

overtopped the dikes. This way the area could benefit from a thin clay deposit which the farmers referred to as natural fertiliser. What this meant was that each winter the land was fertilised by the sea. This meant that both land use and habitation here had to be adapted to these conditions.

Because there was always the risk of a late flooding in the spring or an early flooding in the autumn, the area could only be used as pasture and for hay making. Furthermore, habitation could only be possible at a safe level, and therefore each farmstead was built on top of an artificial dwelling mound. Although the size of farms could vary, generally top levels lay at about 2.50 to 3.00 metres a.s.l., which is high enough to be safe from the high winter tides (Fig 6). The town of Kampen invested a lot of money in building dikes and roads and digging ditches, but a substantial income was earned each year by leasing out land to farmers. This started in the fifteenth century and since 1682 the town kept a record of the 2,342 hectares leased out in 54 farmyards (van Weijdom Claterbos, p. 9; Schrijver 2008, p. 14). At regular intervals the town renewed the lease contracts with all the farmers. This was done by issuing a number of conditions in one general contract, in which each farm stead with its surrounding meadowland was given a number and referred to as Erf 29. As far as dike maintenance is concerned, in the nineteenth century the town began to employ hydraulic engineers who also technically led the process of embankment.

Pastoral land use remained unchanged for a very long time. In terms of water and coastal management, however, the large scale 1825 flood led to changes in dike building. Soon afterwards tops of dikes were raised to a top level of 2.50 metres and even higher at some locations (de Kraker 2010). Dikes along the river IJssel were raised as well. Although it seriously reduced the risk of disastrous flooding no further major changes took place. Not even when the Enclosure Dike was built in 1932, closing off the former Zuiderzee and reducing the danger of flooding from the sea side. Even the process of embankment on Kampereiland continued until 1940 as ever before. The last small polder embanked in this way was the Rechterveld. Dwelling mounds were changed following the old principle of raising them 3 metres a.s.l, a practise which was carried on as recently as the 1930s. After having managed and exploited Kampereiland since 1364, in 1970 the town of Kampen resigned its control over the local hydrology. The regional water board assumed the task of water management, and farmers were allowed to purchase the farms they had formerly leased.

Fig. 6 Dwelling mound on Kampereiland, 2010 (photograph author)

Discussion

In this article three different examples of coastal areas and coastal management have been presented, showing how they came about and were used. Here the sustainability, economic and several social dimensions will be further discussed.

Many salt marsh areas of coastal Brittany and Anjou were transformed into salt making landscapes with salines that mainly needed maintenance in the winter season. During the salt making season there was controlled flooding, but if flooding occurred during the winter season there was material damage to the systems. Maintenance focussed on removing clay deposited in the salines. Changes in sea level, for instance sea level rise, lead to further deposition which could be coped with easily (Buron 2004, pp. 105–109). If this was a gradual process then less clay had to be removed, dikes were raised slightly and some sluices had to be changed. The threats of climate change could thus be easily turned into benefits in a rather sustainable way. Although salt making in salines was well established before 1,000 AD, there were periods of rapid expansion and periods of decline. Each new period of resumed growth largely meant restoring abandoned systems of salines. During the eighteenth and early nineteenth century new coastal areas and areas further away from the coast were opened up. This led to extra costs of removing sediments and transporting salt. It also led to a higher dependency of the employment structure on salt making, because farmland was transformed into salines which rendered farm hands and small peasant out of a job or they started working in the salines.

In Zealand salt marshes were embanked and used as arable for growing commercial crops. At the same time farms and even villages were built in the new embankments. This required the building of high dikes that needed continuous maintenance. If flooding occurred this did not only cause huge material damage, but also led to the loss of human life and livestock. It would also render the arable land less fertile in the short run because of salt penetrating into the soil. Once such a high sea wall was built, and the process of sediment deposition also stopped. Depending on the soil type, in each new embankment the surface level dropped a bit. In particular, the clay soils overlying much thicker layers of peat were likely to subside. Moreover, sand and peat extraction made subsidence of the surface level even worse. Finally, newly embanked polders located too close to the main channels of the Western Scheldt faced the risk of erosion caused by changes in channels moving too close to their dikes. As a consequence of all these factors, living in such embankments could be very risky. In estuaries the process of embankment poses even greater threats because it leads to the funnelling of tides at the far end and thus increases tidal amplitude. In view of present climate change—which is expected to lead to further sea level rise—the pressure on such embankments increases even more. Further embankment at this stage does not seem like a good idea, as it would heighten the difference between sea level and the subsiding polders, which no longer receive influxes of sediment at all. However, tidal amplitude does not continue to increase for ever. If there is a gradual process of embankment, an estuary becomes smaller. At a certain stage it will have become so small that the amount of water entering it begins to drop and consequently tidal amplitude is likely to drop too.

On Kampereiland, seasonal flooding of the pastures is made possible through low top levels of the dikes. The low embankment thus serves to improve the pastoral land, and habitation on dwelling mounds fits in perfectly with this picture. Neither land use nor habitation seems to be much affected by possible changes in sea level. The land is built up yearly by new sediments and dikes here can be easily remodelled. In the past, old dikes were usually removed and the clay was re-cycled in building new ones. This type of land use, habitation and coastal management appeared to be very sustainable until the mid nineteenth century, when the high level of the river IJssel along with severe westerlies caused large scale flooding in 1825. Repairing the many wide and deep gaps in the main dikes was very expensive. It made the townspeople of Kampen realise that measures had to be taken to prevent such disasters from happening again. Therefore, top levels of dikes were slightly raised. This tipped the sustainable balance: the raised dikes stopped the yearly flooding, halting the natural fertilising of the land and rendering pastures less productive. From 1825 to 1933 only some forty cases of flooding have been recorded of which most lasted barely one day or affected only a small area of Kampereiland, whilst a yearly flooding event usually could last for weeks. Still, dikes remained too low, therefore they could not prevent flooding during storm surges. Most of the forty cases mentioned were damaging storm surges. But contradicting all reality the old belief in the old system of annual flooding remained so strong that it kept on dominating dike building and land reclamation on Kampereiland as late as the mid twentieth century.

Comparing the three examples in terms of costs and benefits the following may be said. The salt making industry at Brittany and Anjou offered an annual income. However, this was very much determined by weather conditions, because bad summers could reduce yearly income to less than half (Buron 2004, p. 98). The costs of annual maintenance were determined by upkeep of levees, pipes and sluices and the removal of sediment deposits. Maintenance was labour intensive, but as long as wages were low, this did not pose any serious problems. Additional costs depended on the occurrence of weather extremes such as storm surges during the late winter season, which in the worst case scenario could delay the start of the salt making season by weeks. Sometimes big storm surges put entire systems of salines out of production. This happened in 1548 and 1598 at Bourgneuf and neighbouring towns which went out of business for some time (Buron 2001, p. 92). Such events immediately led to the rise of new competitors such as Guérande and its neighbouring salt towns. Salines that had suffered too much damage could also be abandoned, reverting into a salt marsh which eventually buried the former cultural landscape. The rapid recovery of the salines and expansion during the seventeenth and eighteenth century were largely determined by growing demand for salt, first from the Dutch and later on other nations. Besides the decline of main competitors such as Brouage also enhanced salt production at Guérande exported through the port of Croisic (Delafosse et al. 1960, pp. 39, 96–97; Buron 2001, pp. 106–108, 2006). In spite of the general decline in salt export by the late eighteenth century, fishing on the French Atlantic coast expanded and the home market somehow compensated for the loss of export. In the mid 1870s the salines at Guérande still yielded an average of 16,109 tons per year (Buron 2001, p. 110), but soon afterwards there was a sharp decline in production.

The resilience of salt making coastal communities in Brittany and Anjou also very much depended on the impact of big storm surges, how often they occurred and if neighbouring competitors had also been hit or not. The worst case scenario before 1800 was huge material damage that could put an end to business, but hardly ever caused any loss of human life. The worsening scenario after 1800 was the gradual decline of salt making on the French coast. Whilst the growth of salt production had led to new settlements and the expansion of existing ones, the coastal area had become densely populated. This population depended heavily on the mainly agricultural area to the east for its food supply. Many abandoned salines were gradually changed into farmland, whilst others turned to fishing, agriculture, service industries and finally tourism. Hampered by a number of very bad seasons during the 1930s and wartime right after that, it was not until the post war decades that big companies again stimulated traditional salt making locations. Reorganised paludiers and others professions involved in salt production introduced some new techniques which greatly contributed to the revival of salt making on the French coast and thus the sustainability of the coastal area (Corlay 2006).

In terms of costs and benefits the Zealand Flanders example very much depended on a variety of factors, such as grain prices, growing population and height and location of salt marshes that were about to be embanked. As grain prices went up it became profitable to embank salt marshes and use them as arable for growing wheat. Therefore, until the mid-seventeenth century high grain prices encouraged the process of embankment, whilst low grain prices (1650–1750) slowed it down abruptly (van Cruyningen 2005–2006; de Kraker 2007a). During the nineteenth and early twentieth century a rapidly growing population and a growing market for grain again encouraged the process of embankment. Moreover, the introduction of new agricultural techniques guaranteed a steadily growing yield per acre. This led to the embankment of salt marshes which were not actually high enough yet or were too close to tidal channels, which raised the costs of dike maintenance. As soon as prices dropped, the costs of their maintenance ran too high. If extra costs had to be made after for instance flooding events or the collapse of dikes near tidal channels, this usually led to the building of secondary dikes which reduced the size of the polder. The worst case scenario was abandonment of such a polder. In order to avoid this happening, owners of such polders asked for financial assistance from other polder farmers. Usually they refused, except for cases of large scale flooding when the provincial government took control of events.

The resilience of the embankments in the Zealand Flanders area very much depended on agriculture. Older embankments were usually better equipped to survive at a low market than new embankments, which being an expensive investment suffered heavy losses. From the late nineteenth century onwards the provincial government started new legislation which subsidised dike maintenance of particular polders and reorganised polders into bigger water boards. This process, which was enhanced by the large scale flood of 1953, meant that by 1999 there was only one water board in Zealand Flanders. Before the 1950s dike maintenance had been a matter exclusively for farmers and land owners, but after this time the dikes became everybody's responsibility, and local households and other businesses in the area began to be taxed to maintain the embankments.

The picture of costs and benefits in the Kampereiland area is a different one. Here benefits came from annual flooding during the winter season which guaranteed regularly fertilized meadows. Income was determined by a rather steady demand for dairy products, beef, wool and mutton. The start and rapid growth of the embankments with low dikes coincided with the steady population growth which occurred during the fifteenth and sixteenth centuries. Another episode of land reclamation occurred during the late eighteenth to early twentieth centuries, again coinciding with population growth. A further incentive was that land reclamation by growing reeds and rushes also yielded an annual income. The profitability of land reclamation in the region of Kampereiland led to a market orientated landscape and economy. The area could be maintained at low costs, and set backs only occurred during extreme weather events. In 1570 and in 1825 storm surges caused large scale flooding (Grooten 1998, pp. 9, 12). In 1825 more than 2/3 of the houses were destroyed and about forty barns washed away (Grooten 1998). Besides, repairing the many wide and deep gaps in several dikes cost huge amounts of money. Although no research on this matter has been carried out so far, repairs had to be paid for by the town of Kampen as land owner. For farmers it them took years to earn back the loss of their live stock.

In addition there also was regular flooding caused by the river IJssel, but river flooding was considered less harmful. Finally, a number of flooding events led to a change in the construction of levees which were henceforth transformed into semi high dikes, which gradually degraded the entire system of flood-fertilizing. In effect, the resilience of the Kampereiland community to extreme events led to a compromise between absolute safety and sustainability. The mid nineteenth century compromise of safety by raising dikes did not achieve absolute safety at all, because the dikes were not high enough to withstand extreme floods. The compromise also damaged the sustainability of the system, because winter flooding (fertilizing) was reduced to a absolute minimum and the land no longer received the sediment that kept it fertile.

Comparing the long term sustainable benefits of the three examples shows that the Brittany and Anjou coastal lands continued to silt up naturally and could easily keep up with sea level rise.

The Zealand example is quite distinctive. As soon as high dikes were built, deposition stopped and relative subsidence of surface levels took place. As sea level rises, the relative subsidence becomes worse and the costs of maintenance of the dikes rises. In the long run, discharge of fresh water has to be carried out by pumping stations. Technically this process could continue for a long time, but in terms of sustainability it cannot.

The Kampereiland example shows that as long as flooding during the winter season takes place, the long term sustainable balance can be maintained.. The process of deposition fertilizes the pastures and it can easily keep up with predicted sea level rise. The impact of large scale flooding events during the nineteenth century was so dramatic that the system of low levees was finally changed. At the same time it put an end to the benefit of winter flooding and therefore annual fertilizing. Sometimes there was no winter flooding for a number of years and when it occurred it lasted hardly a day (de Kraker 2010). In the long run it seriously reduced the fertility of pastures and stop the process of sediment deposition rendering it impossible to keep pace with sea level rise.

So what can we learn from the lessons of the past presented by the three examples?

In the future, continuous sea level rise is expected to put more pressure on coastal lands. Those areas that are currently developing without human interference will not suffer serious consequences. These are the salt making coastal lands of Brittany and Anjou. The Kampereiland area also meets all conditions for coping with future sea level rise. However, since it decided to raise its low dikes during the mid nineteenth century and because of the building of the Closure Dike in 1932, this system stopped functioning the way it was meant to. Still, lessons can be learnt from both examples. Building structures to encourage rapid sediment deposition is both a low cost solution to sea level rise and sustainable. Aspects of the system cannot only be applied across Europe but also in coastal areas such as Bangladesh. High population pressure and cheap labour can be used to enhance sediment deposition, build safe dwelling places and still use coastal areas as pasture or semi arable.

In view of future sea level rise the Zealand Flanders example leads to higher costs, because of continuous higher dikes, which have a top level of 10.00 m a.s.l. since 1953. Technically there seems to be no problem at all with carrying this out. However, it does not solve the issue of subsidence. Therefore, a technique of controlled flooding could be introduced at locations where safety allows it (Lases et al. 2009). This implies that water may again flood a polder through a restricted number of inlets during high tides. These inlets are specially built sluices, initially used during the eighteenth century for reasons of military inundation. At the same time the proposed system means that dikes can be kept intact. There is no need to first remove the old infrastructure, because roads and ditches will be buried under a thick new sediment. For the period during which a polder is flooded, it can be used as a water meadow or for the growing of edible marine plants, or as a nature reserve. In this way, flooding may be controlled, and—depending on the rate of deposition—may also continue for a limited amount of time.The process of deposition can be seriously enhanced by growing reeds and rushes obtaining over 1.00 metre of sediments within a decade. Locations for controlled flooding need to be selected carefully; if they are too close to industrial areas, then incoming sediments can be polluted. Looking for compromises between economy and sustainability (i.e. finding cheap solutions that do not damage the ecosystem) often leads to effects that are not anticipated. For example, dredging an estuary such as the Elbe or Western Scheldt and flooding polders on its bank only worsens both the issues of safety and sustainability (Lases et al. 2009). Extra space will enhance tidal amplitude and hence erosion. More accommodation space for water can only be carried out safely in river areas further upstream, not in estuaries of which the access channels have first been enlarged and made deeper. Therefore, if an estuary is subject to controlled flooding rather than dredging, there are benefits which are without costs: deposition is resumed, and the soil is re-fertilized and the area is once more made safe to live in.

Conclusion

This article looked at how communities living in salt marsh areas have organised their coastal defence by using the incoming tides to their benefit. Because Europe has many coastal low lands, three such areas have been selected to look at more closely to identify which area has developed in an sustainable way and at a low cost. Finally we looked for lessons to learn from these examples for areas across the world that face similar circumstances. The examples are the salt marshes of Brittany and Anjou (France), Kampereiland (The Netherlands) and Zealand Flanders (Belgium and The Netherlands).

The French salt marshes were transformed into a salt making landscape with an infrastructure of access channels, different basins interlinked with sluices and low levees. Summer weather conditions guaranteed the crystallising of salt in the saline. It provided people with a highly commercially orientated livelihood. Maintenance consisted of removing deposits and repairs to sluices and levees during winter time. Changes in sea level did not pose any threat, because the system could keep up with these changes and could therefore evolve quite sustainably. Drawbacks were caused by extreme weather events such as storm surges, which caused huge material damage. In the worst case this could put an end to salt making at certain locations.

The marsh area of Kampereiland was transformed into a pasture area. Because of the small tidal amplitude, low dikes were built along with the growing of reeds and rushes to encourage the mudflat to grow into salt marshes. Soon after embankment had taken place more solid dikes were built which were still low enough to enable winter tides to flood the area and render it fertile. Therefore, people adapted by settling on dwelling mounds which were high enough to be safe against high floods. The main livelihood in this landscape was live stock breeding and dairy farming, which became highly market orientated. Maintenance consisted of repairing dikes, cleaning ditches and the upkeep of dwelling mounds. In terms of sustainability, any possible form of sea level rise could be coped with by the annual flooding and deposition of fine clay. Drawbacks were caused by extreme floods. The costs of the 1825 flood were considered too high, therefore dikes were raised. In terms of safety this did not meet the initial demand, because extreme events continued to cause damage. The change was not a success in terms of sustainability either, because winter flooding dropped to a minimum, rendering meadows less fertile and stopping the process of sediment deposition.

The Zealand Flanders example of embankment only used the tides for building up salt marshes. Then this process was stopped by building high dikes. On one hand, this provided a rich area for growing commercial crops from which farmers benefited, especially during periods of rising grain prices. On the other hand, maintenance of such embankments was high and became problematic as soon as grain prices dropped. In the worst case embankments could be abandoned, which happened after storm surges and flooding. Embankments were not very sustainable, because incoming tides were banned and deposition was stopped. It caused gradual subsidence of the surface level. In view of rising sea level this became even worse. Therefore, a technology of controlled and temporary flooding may be introduced again.

There are important lessons to be learnt from these examples. Sustainable land use and coastal management are possible in reclaimed salt marsh areas if there is a modest tidal range allowing continuous sediment deposition to build up the level of the salt marshes. Land use should be adapted to regular flooding, either seasonal or otherwise; livestock ranching and diary farming are appropriate to such conditions. Kampereiland provides an excellent example which demonstrates that it is possible to live in a regularly flooded area if dwelling sites are adapted to cope with high floods. Regular flooding and the consequent sediment deposition would also be the best guarantee against expected sea level rise. In coastal areas this beneficial natural process could be initiated again through controlled flooding.

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